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The Geneva International Centre for Humanitarian Demining analyzed the benefits, potential uses and cost efficiency of miniature aerial photography planes for use in mine action.

by Inna Cruz and Daniel Eriksson [GICHD]

The peaceful use of unmanned aircraft systems (UAS) increases significantly as their cost and complexity reduces. Their use within the military environment has grown exponentially over the past 10 years, and fully autonomous, ultralight, unmanned aerial vehicles (UAV) are now commercially available.[1] Their small mass and soft material reduces the risks associated with use, which was a concern in the past with large fossil fuel–powered platforms. In addition, their autonomous capacity means that they are very easy to deploy, operate and retrieve without the need for an expert operator.[2]

UAS offer promising environmental, cost and efficiency benefits for a whole range of applications from crop-spraying and traffic-monitoring to pipeline and power-line surveillance.[1] These technologies have potential applications in domains such as scientific research, disaster prevention and management, homeland security, environmental protection, communications missions and protection of critical infrastructure (Figure 1).[3]

The potential benefits of using UAS technologies in humanitarian mine action are still being explored. Past use focused mainly on detecting individual mines and explosive remnants of war (ERW) using large, expensive UAS units.

> Unmanned aircraft systems (UAS) include the complete solution and software for flight planning and control, imagery treatment and analysis. Unmanned aerial vehicle (UAV) refers to the aerial platform, the plane itself. Miniature aerial photography plane (MAPP) is a term GICHD adopted to call the UAV used during the feasibility study. UAV and MAPP are however synonymous.

Background

The Geneva International Centre for Humanitarian Demining (GICHD) is running a feasibility study to explore all potential benefits of the use and cost efficiency of fixed-wing, miniature aerial photography plane (MAPP) technologies in emergency operations and humanitarian mine action. MAPPs produce very high-resolution, low-cost aerial photos of hazardous areas (Figure 2).[4]

GICHD's study focuses on fixed-wing UAS in the ultralight micro and mini categories (MUAVs) developed for civilian use.[5] This category of systems dominates the civilian market (Figure 3).[3] Because of their small size MUAVs have fewer legal restrictions than larger UAS.

Images acquired with MAPP can be used to enhance planning, recording and reporting capabilities at different stages of the land release process. Currently, these systems are not deemed adequate to detect the presence of ERW contamination—although indirect indications of contamination could be detected, like the presence of trench lines, barbed wire, impact craters, etc.

In the framework of the project, 20 mine action actors participated in a survey of UAS user requirements to determine existing needs in the mine action sector for UAS technology. Then a mini UAV, the Swinglet CAM, also called MAPP in the scope of the GICHD feasibility study, was selected to test the complete work flow (flight preparation, departure and landing controls, and image extraction). The objective was to determine technical and capacity requirements for MAPP use as well as to identify the most appropriate methodology for imagery processing and analysis. GICHD funded and fulfilled numerous Swinglet CAM flight tests in Azerbaijan, Sweden and Switzerland. Special emphasis was made on the analysis of existing needs of such technologies in the mine action sector.

The project was conducted in a close collaboration with United Nations Institute for Training and Research (UNITAR) Operational Satellite Applications Programme, Swedish Civil Contingencies Agency, Azerbaijan National Agency for Mine Action, Iraqi Kurdistan Mine Action Agency (IKMAA) and Cambodian Mine Action Center.

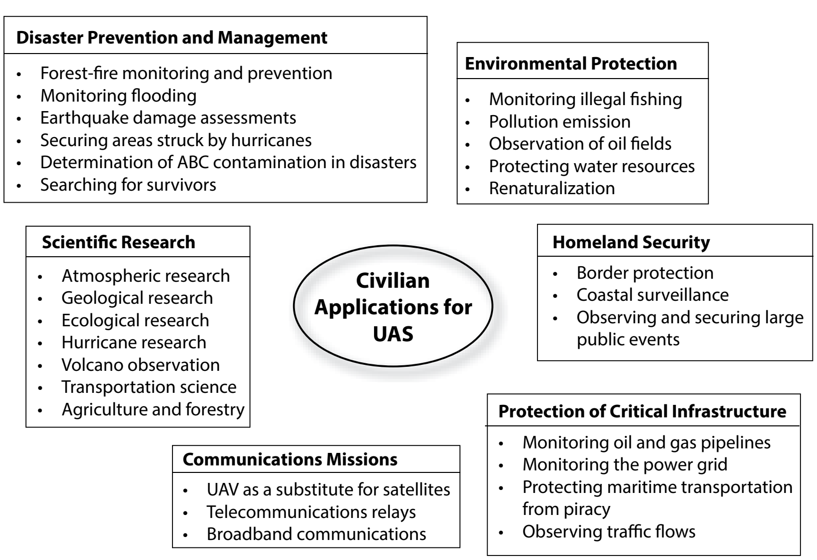

Figure 1. Civilian applications for UAS.
Figure courtesy of Theresa Skrzypietz/Brandenburg Institute for Society and Security.[3]

Figure 2. High resolution UAS imagery (left) and GeoEye satellite imagery (right).
Figure courtesy of GICHD.

Existing UAS in Mine Action

Examples of past UAS use in mine action include the Airborne Minefield Area Reduction (ARC) project. The ARC system was based on a helicopter UAV with optical, infrared and hyperspectral sensors. The ARC consortium in Croatia tested the complete airborne system (Camcopter and cameras).[6,7,8]

More pragmatic solutions to acquire pictures over areas include using kites or weather balloons fitted with cameras. Unconfirmed reports of the use of such devices in mine action come from Southeast Asia.

Sky-Watch, in close collaboration with DanChurchAid (DCA), planned to use the Sky-Watch Hugin X1 quadcopter to survey the extent of contamination in certain areas of Libya.[9] The imagery Sky-Watch can produce is claimed to help in operational planning. However, the tests did not occur because DCA did not receive permission for the flights in Libya.[10,11]

User Requirements Analysis

GICHD conducted an online "Unmanned Aircraft Systems user requirements" survey in 2012 to identify user needs and potential uses for UAS technologies in humanitarian mine action. The 20 respondents were representatives of national and international mine action organizations and nongovernmental organizations, predominantly consisting

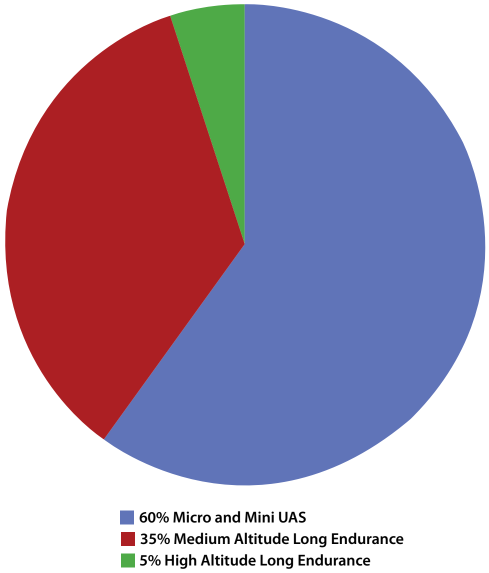

Figure 3. Civilian market for UAS in Europe by category, 2008–2017.
Figure courtesy of Therese Skrzypietz/Brandenburg Institute for Society and Security.[3]

of information-management and operations staff with combined work experience in 14 different mine-affected countries.[12]

The majority of respondents (84%) did not have experience with UAS. According to participants, the main constraints are cost, inexperience with UAS, legal restrictions, logistics and safety and security issues (Figure 4).

The majority of respondents were interested in mini fixed-wing and quadcopter UAS categories. Respondents were less interested in helicopter UAS categories.

Equipment and maintenance costs seem to be an important constraint for widespread UAS use in the mine action sector. The survey showed that the procurement price for an entire UAS should not exceed US$10,000 for the average buyer. The respondents (75%) also expressed the desire to purchase equipment for their respective country program or international organization rather than receive help from commercial companies on temporary missions. Some respondents (25%) indicated that another option could be to ask nonprofit humanitarian organizations for such services.

Video or photography collected by a remotely piloted plane can be stored locally on the camera and retrieved once the plane lands or transfers to the ground station remotely. Receiving real-time surveillance of dynamic situations is important for security operations (e.g., border protection, monitoring the coastline), disaster management operations (e.g., forest fires, floods, earthquakes, storms). Contrary to these time-sensitive operations, survey participants deemed the postflight transmission of the photography data sufficient for mine action applications. This is important, as postflight transmissions greatly reduce the system's size, weight, cost and overall complexity.

Regarding the output product type, the respondents were interested mainly in imagery mosaics (the combination of numerous photos into one large photo) and georeferenced orthorectified mosaics, digital elevation models (DEM) and 3-D models corrected with the help of ground-control points (GCP) to improve geolocation accuracy (Figure 5). The respondents (63%) desired geospatial data accuracy of 1 m or better.

The respondents saw UAS output imagery products as beneficial to humanitarian mine action. They ranked the potential use for high-resolution imagery, as listed in Figure 6.

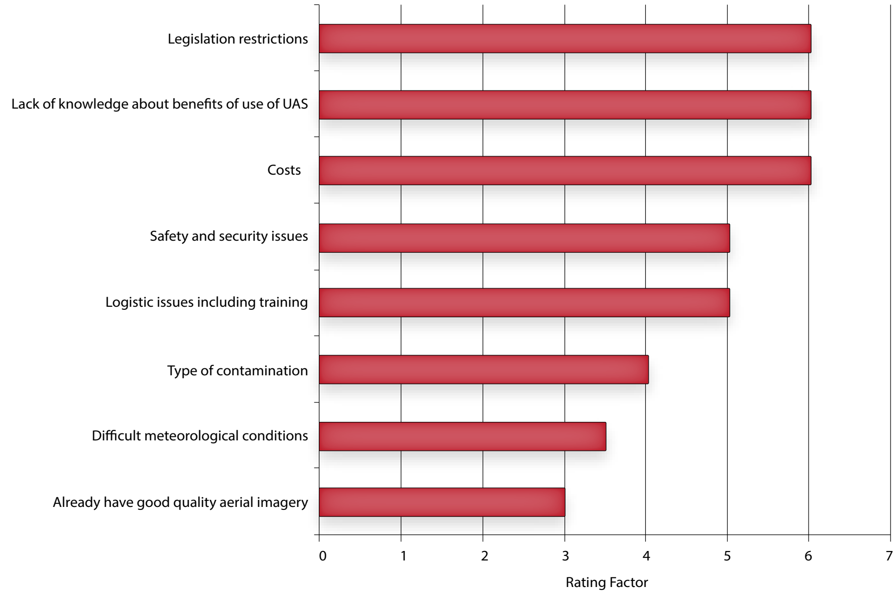

Figure 4. The main perceived constraints of UAS use according to the survey (7 = most important).
Figure courtesy of GICHD.

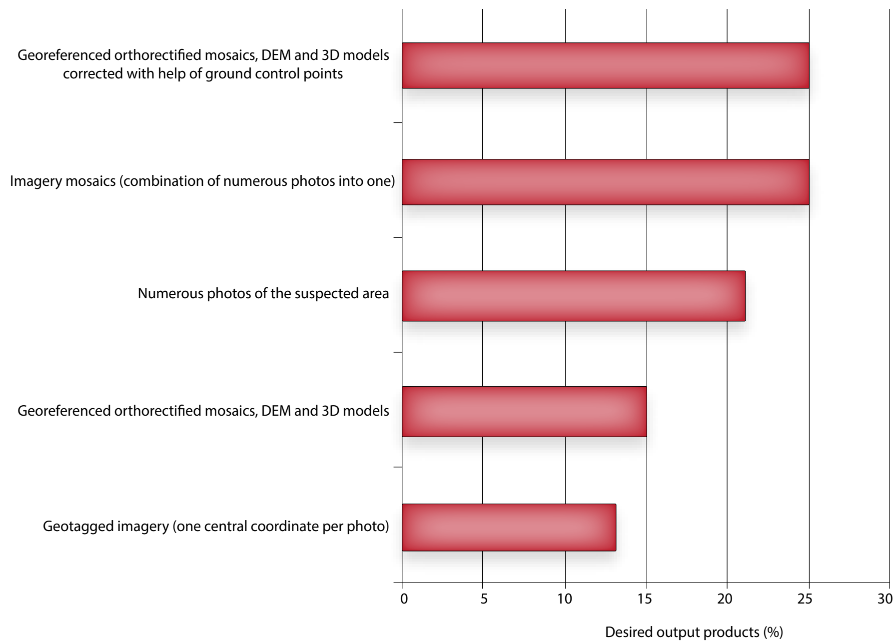

Figure 5. Requirements for the level of the output products (%), according to the survey.
Figure courtesy of GICHD.

Swinglet CAM

GICHD selected the ultralight Swinglet CAM, a 500 g autonomous flying wing produced by senseFly, which falls under the MUAV category, to use in flight tests. Numerous civilian UAS are in this category. Conducting future flight tests of other UAS in the same category will be beneficial for comparison. The following criteria were considered when selecting the Swinglet CAM: accessibility; cost; compactness for an easily transportable system; ease of use; takeoff and landing radius; and robustness, meaning it is easily reparable without special tools.

The Swinglet CAM system includes a u-blox GPS chip, an altitude sensor, a radio setup for a transmitter and an autopilot circuit board. The maximum payload is 125 g. An autopilot operates the UAV independently, keeping it on the programmed flight lines and triggering the camera shutter. Power supply is assured with a small lithium-ion battery, and flight time is about 30 min. The Swinglet CAM can operate in winds up to 25 km/h. The sensor is an off-the-shelf Canon Ixus 120IS camera with 16 megapixels (4000×3000 pixels).[13] The camera setup for data acquisition is managed automatically with autofocus and automatic speed-aperture settings. The autopilot electronically integrates and controls the camera. Integrating another camera in the system at a higher cost is also possible. To protect the camera during takeoff and landing, the camera is shut down. Each image is tagged

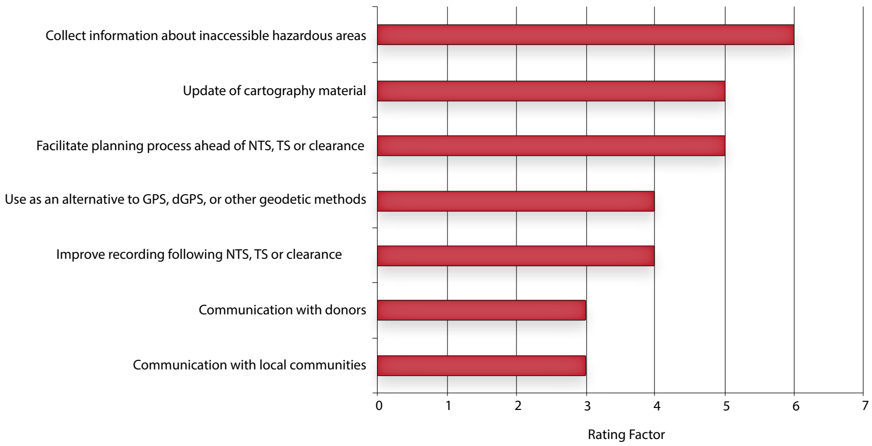

Figure 6. Potential applications of high-resolution imagery in humanitarian mine action (7 = most important).

Figure courtesy of GICHD.

with one grid reference from the GPS sensor. An altitude sensor provides the three orientation angles: roll, pitch and heading.[13]

The Swinglet CAM kit is compact and easily transportable, although the bag does not meet carry-on luggage size restrictions (Figure 7, page 54). The Swinglet CAM does not include imagery treatment software (for mosaicking, georeferencing or 3D modeling) or imagery analysis software.

Flight Preparation, Planning and Control

The included e-motion (electronic monitoring station) software makes flight preparation, planning and control straightforward tasks. E-motion is Swinglet CAM's proprietory user interface: Its main functions are programming the flight plan and photo locations, displaying the position of the Swinglet CAM, modifying the flight plan during the flight, and displaying status, warnings and error messages.[14] During flight tests, e-motion was intuitive. One day of training is sufficient to use the software and the Swinglet CAM as intended. Three GICHD staff members carried out test flights in Switzerland, and one carried out test flights in Azerbaijan and Sweden. Some GICHD staff managed to operate the system with less than a day's training. Using the same Swinglet CAM, up to 10 flight tests were conducted in Azerbaijan, 15–20 in Sweden and 30–40 in Switzerland.

The Swinglet CAM does not need a launch system. One person can launch the device by holding it with both hands and shaking it firmly three times. This initiates the takeoff process if the pre-flight planning and check procedure is completed. Two operators initially encountered problems because the propeller was wrongly positioned, highlighting the importance of the pre-flight checks. After a couple of failed attempts, operators could successfully launch the Swinglet CAM. Once airborne, the autopilot takes control, and the device reaches the programmed cruising altitude.

If the default flight plan is not altered, the Swinglet CAM is set to land at the same point from which it took off. Based on test flights, the difference between the landing point and the takeoff point is between 9 and 40 m, which is attributed to strong wind and local topography. The altitude sensor on our tested version of the Swinglet CAM is not accurate enough to achieve a more precise landing. The alternative is to take manual control of the device, which is risky and requires a very experienced operator. Later models of the Swinglet CAM ship with a more accurate altitude sensor but at a significantly higher cost: CHF10,000 (US$10,754.40 as of 9 September 2013) for the Swinglet CAM and CHF20,000 ($21,508.80) for the new eBee. The eBee package also includes the imagery treatment desktop software, postflight Terra 3D-EB (for mosaicking, georeferencing and 3D modeling), which must be purchased separately for the Swinglet CAM.

The complete MAPP work flow (from flight planning to landing) is quick. In our test flights, the minimum time needed to complete the whole work flow was 45 minutes to an hour. The process could last several days depending on the area size, the weather and the number of flights needed to achieve the desired image resolution.

During flight tests, two failed Swinglet CAM takeoff attempts in Switzerland resulted in the propeller cutting a gash in the wing. These were repaired with the glue shipped with the Swinglet CAM.

Another crash occurred during flight due to operator error while testing in hilly terrain in Azerbaijan. The flight plan was changed while the Swinglet CAM was in the air because the area of interest was not fully covered. The Swinglet CAM was ordered to return to the its home point, which is located 70–75 m above the launch location. After the launch, the plane reaches the home point prior to starting the flight plan. It returns automatically back to the home point after the flight is accomplished and in cases of emergency. The altitude of the home point is static and cannot be changed. When the operator pressed the "Go to Home" button, the flight altitude changed from 130 to 70 m and the Swinglet CAM crashed because the hills were not accounted for. The resulting controlled flight into the terrain separated the battery from the plane. Using the last coordinate recorded by the e-motion software, locating the MAPP was possible. It had not sustained any damage, and after the battery was reinserted it could continue the flight without problems, proving a certain amount of durability and field-worthiness.

Postflight Imagery Treatment

The Swinglet CAM's output is a large collection of overlapping photographs each assigned a recorded GPS position. The raw, positional accuracy of the captured photos is poor because of the ultralight, unstable flying platform. This was the main challenge in the early development of UAS systems for aerial photography. Nowadays, numerous photogrammetry software can automate postflight imagery treatment, making accuracy an easy task. In comparison to the actual operation of the UAS flight, however, this step requires more skill and expertise in order to achieve high-quality imagery.

When using photogrammetry software, the photos combine into one image: an imagery mosaic. During this process, only the best quality pixel of each overlapping image is selected. The same software georeferences and orthorectifies the imagery mosaic. GCPs measured on the ground can improve the geolocation accuracy. More advanced products, such as DEMs and 3–D models, can also be generated.

Table 2 (page 54) gives some suggestions for existing imagery-treatment software depending on the desired product. The processing difficulty depends on the level of desired product, quality of the raw data, geographical position-accuracy needs and the software used.

Post-processing Software

During MAPP tests, senseFly suggested using the Pix4D, called Postflight Terra 3D-EB, automatic photogrammetric technique. The geolocation accuracy is about 1–2 m without GCPs depending on the ground resolution of the original images.[15] Accuracy ranges between 0.02 and 0.2 m for products improved with the help of GCPs.[3] This means that the actual location of a pixel in the image can deviate between 2 cm and 2 m depending on the quality and the method used to georeference and orthorectify the image.

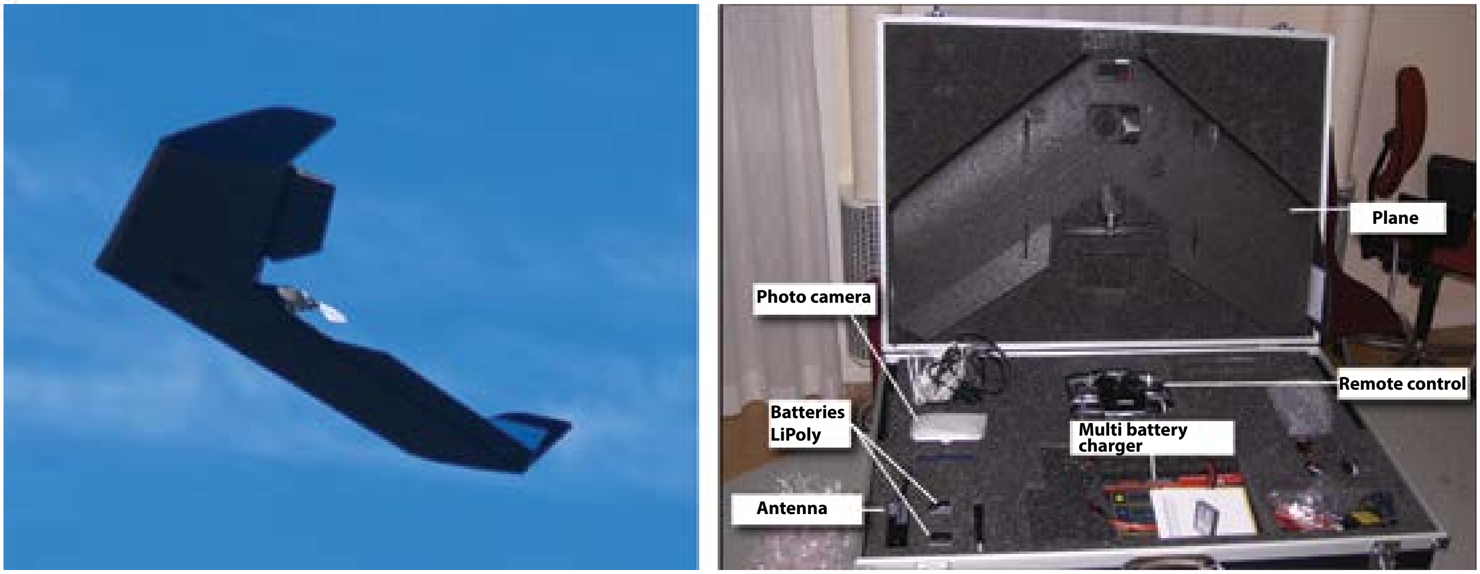

Figure 7. The Swinglet CAM from senseFly.
Figure courtesy of Andreas Nilsson MSB/GICHD.

Stages	Pre-flight preparations Equipment Maintenance	Flight planning Resolution, Altitude, Weather ...	Flight Take-off, Flight time, Landing
Time Estimation	Continuous maintenance	Depending on quality of desired results Min - 5 minutes Max - Several days (DEM, detailed map)	Take off - about 5 min Flight time - 30 min with same battery Loading - Max 2 min

Table 1. MAPP workflow.
Table courtesy of GICHD.

Level of Product	Numerous photos (.jpg for MAPP)	Geotagged Imagery	Imagery Mosaic	Georeferenced and orthorectified mosaics, DEM, 3D
Software Visualization Processing	Many	ArcGIS, Google Earth, GeoSetter	Hugin, Microsoft Image composite editor, ERDAS LPS, Panoweaver, Image Composite Editor, Photosynth application	LPS ERDAS Imagine, Inpho, SOCET GPX, Geomatica, Summit Evolution Professional, Terra 3D

Table 2. Suggestions for imagery visualization and treatment software.
Table courtesy of GICHD.

During UAS equipment selection, special attention should be paid to imagery-treatment software solutions. The Postflight Terra 3D software is also provided through a cloud solution (software as a service). This means that the operator needs good Internet access to upload collected imagery, often exceeding several gigabytes. Postflight Terra 3D provides options for payment per project, which may include several flights over an area of interest. For this project, the basic products (georeferenced mosaic and .kml products) created using this cloud solution cost approximately CHF70 (US$80 as of 2 October 2013) and advanced products (digital surface model and 3D models) cost approximately CHF300 ($330). The total for advanced products included the basic products. The price depends on the number of square kilometers covered, and exact figures must be negotiated with senseFly.

Postflight Terra 3D software is now available as desktop software that does not require Internet access. However, the software's one-time license cost exceeds that of the Swinglet CAM itself. The Postflight Terra 3D Desktop is included in the more expensive senseFly eBee package, but was not included in the Swinglet CAM package.

Using the images captured by UAS without combining them is possible with photogrammetry software. This makes the image immediately accessible after the flight. However, these images are not georeferenced, and the number of images makes it difficult to pick out an image of a specific area.

Image Imperfections

Some imperfections to the output products are inherent to aerial photos at low altitude. For example, Figure 8 shows line and object deformation. These errors are related to the mosaic technique and are caused by each image's optimal perspective in its center.[15]

The deformation of tall objects also presents a challenge. During the flight, the photos are taken from different angles (e.g., see Figure 9, page 56). Trees seem to point in random directions, which is a byproduct of

Figure 8. Line and object deformations in orthoimages.
Figure courtesy of GICHD.

combining images. In each image, trees in the center point toward the camera. However, when combined, images show trees pointing in different directions. To overcome these challenges, one must increase the imagery overlap with more flights and fly along parallel and perpendicular lines. During the flight-planning stage in forest areas, the image overlap parameter should be set to a minimum of 70%.

Meteorological conditions should be carefully analyzed before each flight. The best photo quality is obtained on sunny days in winds lower than 3–4 m/s. Special attention should be paid to shadows. If the aim is to update cartographic material, shadows on the output imagery are undesirable. Conversely, shadows can facilitate the detection of objects (Figure 10).

MAPP in Mine Action

High-resolution satellite imagery and web-based online sources (Google Earth, ESRI, Open Street Maps and Bing Maps) are used on a daily basis by information managers and operators. Depending on available resources and the maturity of the organization, imagery use varies from background mapping for data collection and visualization to very advanced geospatial and remote-sensing analysis.

MAPP technology in mine action operations has great potential as a low-cost alternative to satellite imagery. Dense cloud coverage does not deter MAPPs, which have a high-temporal resolution and are much less expensive than aerial photography from piloted aircraft. When Internet service is unavailable, MAPPs are an alternative solution to Google Earth. Moreover, a MAPP's imagery resolution (3–40 cm per pixel) is much better than that of Google Earth (45–1,000 cm or lower depending on the region).

Due to the geospatial quality of a MAPP image, drawing the outline of a hazardous area is more accurate than walking the same path on the ground with a standard GPS.

Images acquired with MAPP could be used to

- Communicate with local communities
- Enhance reporting capacities to stakeholders outside of mine action programs
- Facilitate the planning, recording and reporting of nontechnical and technical surveys
- Improve the quality of incoming spatial data
- Update cartographic material

Indirect indications of contamination or some evidence of mine/ERW presence might be detected, like the presence of trench lines, barbed wire, impact craters, etc. During rapid-response operations, these technologies could also help inspect blocked roads.

Conclusion

Our survey showed that the mine action sector has an interest in mini and micro UAS technologies. The test flights conducted with the senseFly Swinglet CAM confirmed that UAS technologies are highly mature,

Figure 9. Deformation of trees.
Figure courtesy of GICHD.

Figure 10. Evidence of mine/ERW presence.
Figure courtesy of GICHD.

easy to use, quick to deploy and provide useful high-resolution, georeferenced imagery.

When selecting appropriate equipment, special attention should be paid to imagery-treatment software. This task can be quite difficult and requires specific skills and manual labor. The software is sometimes more expensive than the UAS itself.

Based on our survey and discussions with ETH Zurich, the Swiss Federal Office of Topography and UNITAR, all organizations that use UAS outside mine action, the main constraint for this technology in most countries is opaque legislation. Most countries either equate UAS with commercial jetliners and military technology or to regular radio-controlled models for amateurs. Political and social acceptance is another concern. Privacy infringements similar to those encountered by Google Street View and the risk of accidents, despite Swinglet CAM's low mass, need further examination.

The next step of the GICHD project will be to test MAPP technologies in several mine-affected countries and to build the national capacities of countries willing to use the technology. Future research will be dedicated to imagery analysis and to determining the best ways to use these images. Another goal involves comparing different UAS in close collaboration with partners.

In May 2013, GICHD's senseFly Swinglet CAM was provided to IKMAA for independent testing. GICHD provided three days of training to IKMAA staff, who now use the Swinglet CAM without assistance. This culminated in the first global workshop on imagery and geodetics for mine action, the Geodetics Workshop, which took place 22 July–2 August 2013. The workshop's topic was the use of geospatial-mapping techniques in humanitarian mine action. One session was dedicated to using UAS in humanitarian mine action.

See endnotes page 66

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